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V.

A Scientific Account of the Inner Harbor of Boston, with a Synopsis of the General Principles to be observed in the Improvement of Tidal Harbors.

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Whilst employed in executing the hydrographic portion of the survey of Boston Harbor, and since that time, I have been occasionally consulted as to certain proposed changes in the upper part of the harbor. These inquiries, my acquaintance with the subject and interest in it as a native Bostonian, have led me to make a particular examination for the purpose of ascertaining what alterations have taken place since the survey of Commodore Wadsworth in 1817. Some changes must necessarily have followed from the great diminution of the water receptacle above the channel, from the construction of wharves and piers, from neglect, and from the constant operation of those laws of tidal deposit which were the subject of a previous communication to the Academy.

The gradual deterioration of Boston Harbor is now generally admitted, and apprehensions are felt that the consequences of this deterioration may be, if it is suffered to continue, seriously injurious to the future prosperity of the city. The time seems, therefore, to have arrived, when it is expedient to inquire into the comparative condition of the harbor, using the most accurate means of investigation attainable; to state the active causes of change of which the present condition is the natural result; and to lay down those principles of hydraulic engineering which must be consulted in order that any future constructions, demanded either by the business of the city or the preservation of the channels, may prove beneficial, and answer the purposes for which they are designed. To make such an application of these principles as will form the safe basis of a plan for the general improvement and protection of the harbor may be the subject of a future communication.

In the preparation of this Memoir I have only consulted my associates in the Academy. I have no connection with any private enterprises of construction and improvement. I represent no parties concerned in them.

For the views here expressed I have no other responsibility than that which appertains to me as a member of this Academy; and this responsibility demands that I should make no statement of facts that do not appear to be well authenticated, present no general views except such as are authorized by a fair and reasonable induction, and advance no principles that are not admitted or easily proved.

The Comparative Condition of Boston Harbor.

The charts and surveys consulted or made known to me, in the course of the preparation of this memoir, are the following: —

1. *Carte du Port et Havre de Boston, avec les Côtes adjacentes. Par le Chevalier de Beaurain.* 1776. This is a military survey, and is based on an English survey.

2. *Part of Boston Harbor, by Henry Pelham.* 1777. This also is a military survey.

3. *Carte particulière du Havre de Boston, avec les Sands, les Bancs de Sable, les Roches, les Amaies, et les autres Directions utiles à la Navigation. Reduite de la Carte Anglaise de I. E. S. Des Barres, Ecuyer. Par le Marquis de Chabert.* 1780. This chart is topographical and hydrographical.

4. The chart of Des Barres in the second volume of the *Atlantic Neptune*, 1775, from which I imagine all the preceding have been taken, whether admitted or not; while Des Barres's own chart is partly composed of a survey of the harbor by Mr. Callender, a master in the Royal Navy, in 1659.

5. *The Chart of Boston Harbor, by Commodore Wadsworth.* 1817.

6. The chart made under the direction of commissioners appointed under the resolve of March, 1835.

7. The chart prepared by the Coast Survey, at the request of the commissioners appointed by the resolve of April 16, 1846.

8. To these might be added several others that are taken more or less from the preceding, and have but little original merit or value, with the exception perhaps of one in the possession of Mr. Thomas Richardson of Boston, entitled, *A Chart of the Harbor of Boston, with Soundings, Sailing-marks, &c. Taken from Holland's Surveys. Carefully revised and corrected by Osgood Carlton, Esq., Teacher of Mathematics, Boston. London, published by I. P. W. Des Barres, Esq. Boston, republished and sold by W. Newman, Book and Chart Seller.*

Of all the charts previous to that of Commodore Wadsworth, it may be said, at once, that they appear to be copied from the survey of Des Barres, or of each other more or less, and that, owing to a want of minuteness and of specific description, it is impossible to glean from them more than one or two facts of importance to be mentioned hereafter. This is not a matter of great regret, since it was not till after 1817 that the Milldam was built, the mill-pond filled up, and large portions of the flats inclosed in South Bay and elsewhere, all of which, together with the numerous constructions on the harbor front on both sides, have been the means of promoting, and of facilitating the natural causes of change in the channels.

If the means of accurate comparison were at hand, it would undoubtedly be seen that the alterations during the first thirty-four years after the close of the Revolutionary War were very much smaller than during the second period of the same duration. From 1783 to 1817, the circumstances, or state of things, remained nearly the same; with the year 1817 commenced those great enterprises which, while they mark the growth and prosperity of the city, have essentially affected the condition of the harbor. In the first period, whatever deterioration took place was due principally to the operation of natural causes unaided, or to the laws of tidal deposit controlled by the natural form of the shores. In the second, those causes, and the cases under them, have been multiplied and assisted by numerous artificial constructions.

The comparisons with the chart of Commodore Wadsworth, made in 1817, from an actual survey by himself, furnish very valuable information.

The life of this officer, every passage of which is stamped with honor and usefulness, having but just been brought to a close, his work ought not to be mentioned without a passing tribute to his memory. Having had the pleasure to sail under his command, and to be associated with him confidentially in important and interesting affairs, I knew him well. He was possessed of a simple uprightness of mind, and zeal and fidelity in the performance of his duty, which give a high authority to whatever came from his hands. In bearing testimony to these intrinsic qualities of his character I am performing a most grateful duty.

The most useful information obtained from the comparison of the Coast Survey chart of 1847 with the chart of Commodore Wadsworth, relates to the diminution in the breadth of the channel between Bird Island and Dorchester Flats.

On the chart of the Commissioners it will be seen that there are four cross-sections. The lines of these sections have been transferred to Wadsworth's chart, and the breadths measured between the six-foot and the fourteen-foot curves. The first of these curves, it may be observed, cannot be defined so accurately on the old as on the new chart; the precision and minuteness in details of the present mode of construction were not then practised. The *six*-foot curves have been traced on Wadsworth's chart from the soundings by myself, but the edge of the *dotted* surface is described on the chart itself as the *fourteen*-foot curve, and this last limit, therefore, is strictly exact. The following tables exhibit the breadths of the sections on both charts.

Between the six-foot curves: —

	Wadsworth.	Coast Survey.
Cross-section No. 1	4350	3333
" " " 2	3000	3104
" " " 3	3600	3104
" " " 4	2700	2167

Between the fourteen-foot curves: —

	Wadsworth.	Coast Survey.
Cross-section No. 1	3150	2500
" " " 2	2700	2650
" " " 3	3000	1833
" " " 4	1200	708

If these figures are summed up, it will be found that, in the first case, the mean loss of breadth in this part of the channel has been four hundred and eighty-five feet; and in the second case, five hundred and eighty-nine feet. The average of the two is five hundred and thirty-seven feet.

Section No. 4 crosses the harbor at the narrowest part of the entrance above Castle Island, that is, at the buoy of the Upper Middle, and here the loss is four hundred and ninety-two feet. Again, there is a point on the northwest part of South Boston Flats, where fourteen feet is marked on Wadsworth's chart; on the same spot four feet only is given by the Coast Survey chart, showing a loss of ten feet in thirty years.

The fourteen foot-depth has been carried out by the encroachments on the channel, if taken in the nearest direction, four hundred and fifty-eight feet; but much farther if measured on the line of the section, that being the direction in which the Flats have gained most rapidly at this point. On the opposite side, there was apparently nine feet in Wadsworth's time, where there is now four; the loss of breadth between these two depths appears by the same comparison to be three hundred feet.

The zero of reduction of the soundings on Commodore Wadsworth's chart, or the plane of reference, is said to be low water, by which is evidently to be understood mean low water. This is the common plane of reduction, and any departure from it would have been specially mentioned. The depths at Charlestown Bridge are known to be the same now that they were when the bridge was built; and the soundings in this vicinity agree with those on the Commissioners' chart, with which the comparisons have been made, the difference in the reduction of the two charts being taken into account.

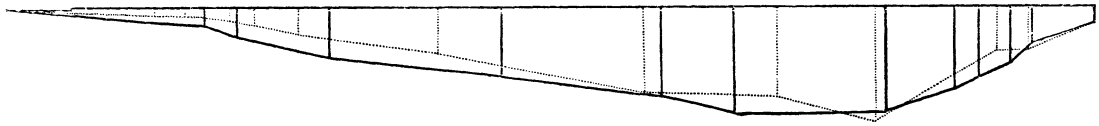
The plane of reference adopted in the general chart of Boston Harbor, executed by the Coast Survey, but not yet published, is mean low water. The depth of water on some rocks in the lower harbor given in Wadsworth's chart coincides with the Coast Survey determinations. Finally, the mean rise and fall of common and spring tides, according to Wadsworth, harmonize better with the reduction to mean low water than to any other plane. This question of the reduction of the soundings is thus carefully considered on account of its important bearing upon the preceding measurements. Their strict accuracy depends upon the standard being correctly ascertained. If, however, contrary to all the evidence in the case (and the comparison of the depths on the rocks leaves but little room for doubt), the very lowest observed or recorded tide should have been used by the Commodore, the loss of capacity in the main ship-channel, though less than above stated, would still be alarmingly great.

The transfer of the sections of the Coast Survey chart to that of 1817 has been made by means of rectangular coördinates, the axis of abscissas being drawn through two distant points that had remained unchanged in the interval, and the centre being the draw of Charlestown Old Bridge. The measures taken on these sections harmonize with each other. Others might have been added, but these are abundantly sufficient to answer the purpose in view.

To the foregoing facts is to be added another more conclusive proof of the deterioration of this part of the harbor, which results from a comparison of the chart of the Commissioners of 1835 with that of the Commissioners of 1846.

It is well known that the former survey was made with extraordinary minuteness and exactness. The precise form of the bottom is laid down in measures of depth below the coping of the dry dock, and the same plane of reference was adopted for the latter survey. The means of comparison, therefore, are strictly accurate, and the results are reliable. The survey of the Commissioners of 1835 extended so far below the wharves as to include the cross-section No. 1 of the Commissioners' survey of 1846.

The area of this section (at low water) is on the former seventy four thousand eight hundred square feet; on the latter, sixty two thousand one hundred feet; showing a loss of twelve thousand seven hundred feet in the water capacity of this place. The breadth of this section on the former is three thousand nine hundred and sixty feet; on the latter, three thousand five hundred and forty-six feet; showing a decrease of four hundred and fourteen feet. The profiles of these sections here presented exhibit the change in the form of the bottom.



It is worthy of notice, that the deposit is principally on the extreme sides of the channel, and that there is a slight increase in the depth in the *middle* of the channel, owing to the loss of capacity. The section under examination crosses the part most affected by the great changes and improvements on the East Boston side during the last fifteen years. And the influence of these changes has been increased by the filling up of the South Bay, and the great decrease of that reservoir in the same time. Another section made to the eastward of the former shows a loss of breadth of about five hundred feet, though the change in the form of the bottom is less marked.

But it is not necessary to multiply cases. The object in this part of this memoir is to communicate the evidences of deterioration, and enough has been adduced to prove the most interesting fact that can be stated with regard to Boston Harbor, and that is, the fact, that, at the inner threshold of approach to the upper anchorage, to the wharves and landing-places of the city and its environs, important changes have been for some time, and are now, in progress, which demand serious attention. And it must be remembered that this fact is the more worthy of consideration on account of the great increase in the size of vessels of commerce. To meet this alteration in the draught and capacity of steamers and merchant-ships, the channels and roadsteads of the harbor should be enlarged, and not diminished.

In this part of my subject it only remains to mention the filling up of the Fore Point Channel. And here the information contained in the old charts above mentioned appears to be satisfactory. Although nothing is known of their modes of reduction, and their statements concerning the tides conflict very much with our present knowledge, yet they concur so fully in assigning a much greater depth to this channel than now exists, that their combined authority cannot be slighted. It is strengthened, moreover, by Wadsworth; and it must be admitted without hesitation, that during the present century the average depths in the Fore Point Channel, below Summer Street wharf, have diminished one half. On the spot the most favorably situated for the accumulation of silt, the loss between the years 1836 and 1847 was more than two feet. This is authentically determined by means of the Commissioners' charts of those years. To all this is to be added the concurrent testimony of intelligent individuals, owning property or living in this part of the city, and having occasion to notice the changes in progress.

From the foregoing recital of the proofs of deterioration in the main ship-channel of the harbor, a deterioration slow and gradual, certainly, but which, if suffered to continue, must in course of time impair the commercial advantages of the city, I pass to the treatment of the natural causes, by the operation of which, assisted as they unavoidably are by artificial constructions, this injury is produced.

The subaqueous deposits in Boston Harbor may be separated into three classes, the *broad flats* attached to the dry land, from which they have been extended by gradual accumulation, of which the South Boston and Quincy flats are examples; the shoals and banks connected with the land, which make out in a more or less pointed form, being projected like *spits* into the channel, and having deep water on both sides of them, of which the spit to the eastward of Castle Island is an example; and detached shoals wholly disconnected with the land, and surrounded by deep water, of which the shoal in the Mystic Channel (on a small scale), and the Lower Middle, and the shoal to the north of Rainsford's Island, are examples.

These deposits consist of the silt of the rivers, or of the degraded materials of the neighboring lands, or of both. They are created by the action of the tidal currents, and this action varies under different circumstances, as these distinct forms indicate. The different forms also run into each other and unite under the combined influence of the various modes of action. The *broad flat*, or "bay deposit," as I have elsewhere named it, is the greatest in extent. It is a skirt of shoal ground, continuous with the beach, and running off some distance under the water, and is formed in those places which recede in the manner of a bay from the main passages of the harbor. The current carried towards the sides and bottom of the bay loses its velocity by degrees as it meets the resistance of the shore; and in bays of every dimension there will be more or less conflict of the tidal streams arising from their approaching each other at last from different sides of the bay. The quiet condition of the water produced by the first of these causes, and the eddying action following the second, are states in which the water drops its burden with facility. The external outline of the bay deposit will depend chiefly on the conflict of the tidal streams.

The *spit deposit*, running off from the land (whether an island or the main shore), is created by a twofold action of the tidal current. *First*, when a tidal current freighted with suspended matter presses on a point of land, beyond which it expands into a more open space, it falls into eddies beyond the point, and these eddies again are favorable to an accumulation of the suspended matter. The point or prominence serves as a nucleus to a shoal or bar joined to the land. The stream presses with accumulated force upon the point, eddies around it, and loses its velocity by diffusion. This is so common, that there is found on all alluvial shores, at every point and headland around which the tidal currents turn, a shoal of greater or less extent, joined to the land, and making a continuation of it. The precise position of this shoal with regard to the point, that is, whether inside or outside, or in a line with the point, depends upon the strength of the current, the depth of the water, and other circumstances. But, *second*, if the land in question is an island, there will not only be the eddying action just described, but a case of conflict will occur arising from a division of the stream by the island on the one side, and the meeting of the two branches approaching each other from opposite directions, on the other side. These counteracting forces create a space of still water. The combination of these two separate modes of action increases the amount of the deposit, and alters its form. Under these conditions it will have more of the character of a bank or flat. Boston Harbor, being filled with islands, abounds in examples of this kind of deposit. They are found on two or more sides of the islands, being formed, of course, by the currents of the ebb, as well as of the flood tide.

Lastly, the detached *shoals*, which are isolated deposits in deep water, result also from the tidal streams being arrested in their direct course, and being brought into that state of eddies and of rest in which, as has been said before, the suspended matter readily subsides. The place of these shoals may be decided by natural inequalities of the bottom, which, interrupting the stream, take up a portion of the matter and cause eddies; or it may be owing altogether to the meeting of two or more streams from different sources or directions in a central spot, around which they gyrate and fall into repose. The bottom in the lower part of the harbor is rocky, and, as there is a rock near the shoal north of Rainford's Island, we may assume that the position of that shoal has been determined by a nucleus, a natural unevenness in the bottom, as in the case first described. But the small shoal in the Mystic Channel is the simple result of the conflict of the stream of the channel on the ebb with that returning from Chelsea Creek. This shoal has been bored by Mr. Williams of Charlestown, and found to consist entirely of soft mud; that is, there is no perceptible nucleus. The Lower Middle probably belongs to the same class, although a single rock is found near the shoal.

Although pains has been taken to classify the deposits according to their characteristic forms, yet it is not to be understood that these precise forms can be distinctly traced in all, or even in many cases, because, as before said, the several modes of action of the tidal currents, or the causes of deposit, are combined in their effects, and produce complicated results. For example, the broad South Boston Flats have the general character of a bay deposit; but this character is modified by other causes. They have accumulated by means of the gradual and long continued deposits made by the currents of the ebb returning from the Charles and Mystic Rivers and from Fore Point Channel, and in a less degree by the current of the flood, divided by Castle Island into two branches, which meet above the island and bring in the muddy water of Dorchester and the neighboring flats and the discharges of the Neponset. Upon the surface of the flats generally the water is for a large part of the tide in a quiet state, the currents having no appreciable velocity or determinate direction. That part of the flats situated between Castle Island and South Boston Point has been built up by the action of both tides. As the ebb of the upper harbor meets that of Dorchester Bay in this space, so also there is a confluence here of the two branches of the flood, one of which passes to the north, and the other to the south of the island. The result of this double confluence is an excessive increase of the deposit in this place. Between Castle Island and the Point, some threadlike channels or drains are still preserved, but they are of no value to navigation. It is nearly, if not quite, possible to pass on foot from the island to the Point at extreme low water.

The increased amount of the deposit at the Upper Middle, where it takes a more pointed form, and projects far into the main channel, shows in a prominent manner the double action of the confluent divisions of the flood, and of the greater or less conflict of the concurring streams of the ebb that finally approach each other from different extremities of the bay in the manner previously described as characteristic of the bay deposit. And this feature of the bay deposit is strengthened by the opposition, as far as it goes, which the ebb current from Dorchester Bay presents to the easy course of that part of the ebb current which tends to drain the South Boston Flats by passing between Castle Island and South Boston Point.

But the conflict of the stream from South Bay, through the Fore Point Channel, with the ebb passing down from the upper harbor, and winding round on the South Boston Flats, gives rise to that other striking peculiarity of the deposit, its pointed and projecting shape on the borders of this channel. The water is diverted from its direct course to the bay, running almost at right angles to it, and the channel is constantly getting longer and shallower by means of this accumulation. It will be seen by an inspection of the map, that there is a remarkable correspondence between the outline of the flats and of the shore, the protuberance of the Upper Middle answering to that of the headland of the heights. On the opposite side of the channel there is a similarity in outline between the flats and Governor's Island, especially in the spot making off from the south point.

These flats immediately round Governor's Island have the twofold character of deposits such as, on alluvial shores, always attach to points and headlands, and of deposits resulting from the confluence of streams approaching each other from opposite di ections. The growth of the banks on both sides of the channel is probably now less rapid than it has been on the external borders; it will continue to diminish. And the reason of this diminution is pregnant with instruction; *it is the gradual narrowing* of the channel that lessens the accumulation, the water being made so much more rapid in its course by this contraction, that it carries its burden beyond this point to drop it in a more favorable place.

It is perhaps in this *narrowing* of the channel, and the greater tendency to deposit on the *sides*, that the explanation is to be found of the positive declaration of the late Mr. Winslow Lewis, that there is now, somewhere in this part of the channel, seventeen feet of water, where in 1814 there was twenty-one feet. It may be an instance similar to those made known by the comparisons with Wadsworth's chart. Still, this deterioration is going on; the *maximum* velocity on a bank of gradual slope must, in the highest parts, be insufficient to disturb the bottom.

Having pointed out the mode of operation according to which the tidal streams create deposits in Boston Harbor, it is worth while to turn for a moment to a consideration of the peculiar character of the harbor, and of the artificial changes which have assisted the working of natural causes. Of good tidal harbors on alluvial or other shores, possessing the means of self-preservation, there are several distinct kinds. There are those which are merely river-courses, as that of Philadelphia and that of Savannah; those which are bays forming the receptacles of rivers, as that of Hampton Roads; such again as are kept open by a double communication with the sea, as Edgartown; such as, having the bay form, not only receive a river, but have a double communication with the sea, as New York; and lastly, those which, like Boston, have large reservoirs or basins behind the port, receiving great quantities of tidal water, and keeping the channels of the port open by the scouring power of the ebb tide. Though the Charles and Mystic are called rivers, they are chiefly to be regarded as valuable reservoirs, the latter being a short drain for Mystic Pond, and the former being affected by the tide only as far up as Watertown. All harbors that have neither land-water nor back-water have a tendency to fill rapidly, and when not very deep, like Wellfleet and Plymouth, soon lose their usefulness; and, in the same manner, all tidal harbors like Boston have a constant tendency to deteriorate. The gradual diminution in capacity of the reservoir, or, in other words, the gradual growth by accretion of the flats and marshes above Boston, as the South Bay, the Back Bay, and the Mystic, is well known to every one who has occasion to observe them from time to time. The deposits by which this gradual increase of the land is finally effected, in the places here spoken of, occur principally on the flood tide. At "slack-water," as it is called, the sedimentary matter will subside in every part of the harbor; but it is not suffered to rest in those places where the *maximum* velocity of the current is sufficiently great to move it again on the returning tide. That part of the deposit of the ebb which is left on the borders of the flats will be carried farther up by the transporting power of the flood, increasing in strength as the tide rises; but if this matter be left during the period of still water between flood and ebb on the upper and inner edge of the flats, it will not be carried off again, because at these points the ebb stream, having no back-water to assist its momentum, never acquires velocity enough for that purpose. It soon, in fact, leaves these higher spots bare. A single illustration, which has been mentioned by Professor Treadwell, suffices to convey an idea of this gradual accumulation. When the Milldam was built, a barrel of tar in a good condition was found buried several feet in the soft mud.

In this manner the capacity of the reservoir is diminished by natural causes, of which alone I am now speaking; and as the reservoirs become smaller, the united sections, or capacity of the channels, by which the water is returned to the sea on the ebb, will necessarily undergo a similar reduction. A diminution of the reservoir occasions an injury to the harbor proportional to the space lost; it reduces the size of the channels simply because less water requires a smaller passage, and is not capable of keeping open the original passage.*

This description of the character of Boston Harbor opens the way to a brief enunciation of the leading principles which should govern any plan of improvement, either special or general.

The first fundamental principle to be observed is the preservation of the water receptacle, to its fullest extent; though not necessarily in any actual or particular form.† Tidal mud-lands may be occupied to advantage, provided compensation is made by deepening the reservoir, and adding to the quantity of the water in the reservoir. The velocity being, in general, proportional to the square root of the depth,‡ and the quantity of water proportional to the depth multiplied by the velocity, it follows that our reservoirs could be, at any time, improved for scouring purposes by excavating systematically the flats which are bare at low water. Owing to this law of velocity, fully established by experiment, and resting on the highest authority, a water receptacle of one hundred and eighty acres in area, having eight feet of water on it, which it receives, on the average, at every flow of the tide, would only be equal to one of eighty-four acres, receiving and having ten feet, that is, would only be equal to it in power to keep the channel clean and sweep away the loose deposits.

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* The diminution in the reservoir caused by dikes, embankments, and made land, gradually produces of course the same effect. It is stated by William P. Parrot, Esq., Civil Engineer, that the area of the peninsula has been increased to three times its original size by this filling-up process. In this manner the action of the natural causes of deterioration is greatly promoted; but as the purpose here is only to lay down general views and principles, it is not necessary to dwell upon the significancy of this statement.

† The English engineers generally.

‡ Zendrini, and others.

This question of the conservation of the reservoirs is to be treated relatively as well as absolutely. During an examination before a committee of the House of Commons, the following interrogatory was put to Mr. John Scott Russell by Mr. Hume: "Do you mean to say that a considerable portion of land might have been inclosed, provided compensation had been made by an addition of water by deepening the channel?" To which Mr. Russell replied, "Perfectly so!"

But the fact that the diminution of the reservoir leads to the diminution of the channels, a smaller quantity of water with less velocity requiring less water-passage, conducts, by an inverse process of reasoning, to the second principle: —

The contraction of the water-passage, or the union of the waters into one channel, and the cutting off of the secondary and lateral channels which conduct the water away from the main channel, and destroy its power and usefulness by wasteful diffusion.*

But while putting into practice the second principle, there are some subordinate principles, the effects of which are to be observed, and which lead to other fundamental principles.

1. When the waters flowing in several channels are united into one channel, the capacity of the latter will be less than the sum of the capacities of all the channels, before the union was made; that is to say, the union of the different passages into one will not lead to a corresponding augmentation in this single passage. This is established by experiment, and confirmed by observation in nature.

2. The apparent contradiction contained in the above statement is explained by the augmentation of the velocity in the main passage, which, under the most favorable circumstances, *might* be equal to the sum of the velocities in original channels.†

It has been found, for example, by experiment, that, if a stream equal to one half the water in the receiving or main channel was added, and afterwards another half, the quantities in the receiving channel being successively 1, 1½, 2, the height in the latter was apparently the same, while the velocities and quantities of the fluid increased in the same proportion; namely, 1, 1½, 2. Again, when the augmentations to the quantity in the receiving channel were in the ratios of 3, 4, 5, 6, and 7, the increase in the height of water in this channel was only $\frac{1}{48}$, $\frac{1}{24}$, $\frac{1}{16}$, $\frac{1}{12}$, and $\frac{1}{9}$, respectively. And, by a contrary proceeding, if several tributary streams are successively let off, the dimensions in the height of water in the receiving channel are found to prevail in the same proportion as the augmentations.* Experiments by Genneté, Guglielmini, Pitot, and Bossut establish the same fact in nature; that is, that the effect of the affluent, especially where it seconds by its direction the thread of the receiving stream by making with it a very acute angle, is not to augment materially the section of the latter, but to give to the combined current a velocity approximating nearly to the sum of the velocities of the tributary and recipient.

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* A. I. C. de Fontaine.

† Guglielmini.

3. This result from the union of several channels into one, or the concentration into one channel of a volume of water which has previously escaped through several channels, in producing an augmented velocity, leads to the statement of a third fundamental principle; which is, —

The limitation of the channels with a due regard to this: that the velocity be not increased to a degree that would be inconvenient to navigation.

4. And as, in the case of a tidal stream, the water that passes through all its sections in equal spaces of time will be equal for every part of the channel, or, in other words, as the medium velocities in the different sections of the channel will necessarily be proportional to the amplitude of the sections,† we arrive at the fourth fundamental principle; which is, —

That the volumes and mean and extreme velocities of the water passing through the narrowest part of the new or improved channels, at ordinary, extraordinary, and mean states of the tide, are to be calculated and used as strict guides in the projected plans of operation. And

5. As obstructions in the natural flow of the water lead to a destruction of that uniformity in the *mean* velocities in which the accelerating force is equal to the retardations, and consequently to sudden and violent states of the current, and as such obstructions create eddies which destroy a part of the moving force of the current on the borders of the channel, and give rise to conditions favorable to deposit, so we are led to a fifth fundamental principle; which is, —

The adoption of such forms for the channel as give an uninterrupted flow to the water; and these forms must be derived, and can only safely be derived, from observations.‡ And further, —

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* Genneté's experiments, cited in the *Report on Hydraulics*. *Proceedings of British Association*, Vol. III.

† Abbé Mann, Castelli, &c.

‡ A. I. C. de Fontaine.

6. As, in a channel of irregular boundaries, the greatest strength of the current is found to be, according to circumstances, on one side or the other, leaving on the side opposite to it an eddy, or a space of still water, or even a current running in the inverse direction, and coming in conflict at the turning-point with the main stream, (a counter-current as it is called,) and as these conditions are favorable to deposit;* and

7. As the deposits caused by such irregularities tend continually to divert the current from its proper channel, and may even, as in the well-known case of the Mystic, completely alter the channel, closing the old and opening a new one; so we are led to observe a sixth fundamental principle; which is, —

That the limit or boundary lines of the channel should be as regular as possible, coinciding with the natural course of the waters; and it would even be desirable to have the sides of the channel steep, if practicable, because, —

8. The velocity of the current is very much diminished on sides of gradual slope, and the suspended matter, therefore, is carried there to be deposited.

The preceding statement of the importance of adopting such a form of channel as will allow a natural flow to the water, of making the bounding lines of the channel regular, and of avoiding obstructions to the current, however comprehensive it may seem to be, still leaves room for the introduction of another fundamental principle similar to those just stated, but derived from the following distinct considerations: —

9. It most commonly happens that, in tidal harbors, the channel or natural course of the water from the receptacle, or river-basin answering the purpose of the receptacle, is circuitous and indirect. Where the natural channel by which the back-water so passes to the sea is direct, as in the inner harbor of New York from the North River to the Narrows, it requires no artificial construction to *improve the form* of the channel, or to *change its direction.* But in the ordinary cases first mentioned, in which Boston Harbor is embraced, *improvement of form* and *change of direction* may be necessary.

10. Now, since the water does not rebound as a mass from an opposing wall or surface, like an elastic body, (a fact I should consider it wholly superfluous to mention, if the opposite opinion had not been maintained by respectable engineers,) but, on the contrary, its currents follow adhesively the changes in the form and direction of that surface;

11. And since we observe in nature, that, wherever one of the bounding sides of a channel retreats back from the former line of direction, there is invariably a deposit opposite the retreating point, we are conducted to a seventh fundamental principle; which is, —

That, where one of the sides of a channel is altered by an artificial construction, the line of this construction should be made uniform and continuous, complying at the same time with the principles previously laid down.

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* Abbé Mann.

12. When the angle of meeting of two streams is a right angle, or approaches a right angle, a deposit will occur at the place of junction, broad at the base and narrowing towards the external termination, the effect of which is to make, *by a natural process*, the angle of meeting acute, as in the case of the deposit at the point of union of the Mystic with Chelsea Great Creek. Thence we derive from the observation of nature the eighth principle; which is, —

That, where lateral streams are diverted into the main channel, or flow into it, they must be made to enter in a direction coincident with that of the principal current to which they become auxiliary.*

The ninth principle directs that the effect of the contemplated alterations on the transmission of the tide-wave should be studied. The experiments of Mr. Russell show that the rate of transmission of the tide-wave depends on the form and depth of the channel; and he specifically states the numerical terms of this relation. Now it is evidently of importance that the tide-waves should reach, as soon as possible, the highest navigable point in the receptacle; partly because it will add to the height of the water, and still more because it lengthens the time during which the water will be sufficiently high for navigation. To solve this important problem, we are to make use of the numbers furnished us by Mr. Russell's experiments.

The last principle to be specified here is this; that, as all plans of alteration in the harbor should have for their first object its improvement for the purposes and conveniences of commerce, so they ought to be made with a careful regard to the wants of harbor accommodation, and to the best and most permanent interests of the owners and proprietors directly concerned in their execution.

It was my wish and expectation, when this memoir was begun, to be able to present with it a plan of improvement of the harbor, such as might serve at least as a general basis for the application of the foregoing principles. But any plan worthy of the consideration of the Academy, or entitled to public confidence, must be accompanied by observations and calculations, which I have not found leisure or opportunity to make. Plans made in the study, without observations in the field, and without calculations determining their consequences, may be very erroneous, and cannot safely be trusted. A reference to the principles laid down in this memoir shows the nature, importance, and objects of these observations and calculations. All the data upon which such a plan is founded should be fully and distinctly communicated, in order that they may undergo strict examination and complete discussion. This part of the subject is of necessity, therefore, indefinitely postponed. I cannot, however, take leave of it for the present, without expressing the opinion that the plan of construction on South Boston Flats contained in the partial report of the present Commissioners, dated March 22, 1851, is not suited to accomplish the declared objects, — which are, "to improve the channel and at the same time to enlarge, in the best practicable way, the wharf and dock accommodations of the city, to meet the new demands of its growing commerce" (p. 14), — but that it will injure the main ship-channel in one of its weak places, by causing an increase of deposit on the side of the Bird Island Flats, by making it more crooked in this part, and by lessening its capacity; at the same time it affords no additional accommodations to commerce of permanent value and utility, and threatens to hasten the destruction of Fore Point Channel.

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* Abbé Mann.

One of the purposes of this memoir has been, to impart the evidences of deterioration in the upper basin. Having these evidences, it was thought expedient, especially when my previous relation to the subject is considered, to make them known. But to prevent any unnecessary apprehension of the immediately fatal consequences of this deterioration, and to do justice to our admirable harbor, unsurpassed in its convenience, security, and ample dimensions, as it is rarely equalled in its beauty, it may be well to compare it with a few of the principal maritime ports of the world.

At New York (to begin at home) there are twenty and twenty-one feet of water on the bar, and the mean rise and fall of tides is five feet; the depth at the entrance of the inner harbor of Boston is eighteen feet, and the mean rise and fall of the tides ten feet; making the average depth in the two places about the same. Boston, however, enjoys this double superiority, — that, while at New York the bar is at the outer entrance, and ships must keep the sea until they are able to pass it, at Boston the bar is at the entrance of the inner basin, vessels are landlocked when they reach it, and, if compelled to wait for the tide, can lie in safety; and Boston, moreover, has several excellent roadsteads, in which New York is comparatively deficient.

At the entrance of the estuary of the Mersey, there are only eleven feet of water at low spring tides; but the rise of tide varies from twenty-one to thirty-one feet. The construction of a new harbor of refuge, at great cost, in this vicinity, is one of the splendid enterprises in which the British are now engaged. The harbors of Dublin are artificial; a bar prevents the entrance of large vessels into the river, and the navigation of the bay is very dangerous in stormy weather. The channel of the river Clyde above Greenwich is only three hundred feet wide, and at Glasgow there is now, after all the remarkably successful improvements made in the navigation of the river, only nine feet of water at low neap tides.

Hamburg, the greatest commercial city of Germany, perhaps of the Continent, can only be approached with safety at all times by vessels drawing fourteen feet of water, though vessels drawing eighteen feet can come up with the spring tides. Marseilles, the great emporium of the South of France, the centre of nine tenths of the commerce of France with the countries bordering on the Mediterranean, has for its port a basin three thousand feet long, and quite narrow, having only sixteen or eighteen feet of water at the entrance, with no perceptible tide, and kept open only by the incessant use of dredging-machines. The port of Havre is kept clear by artificial means.

But the best idea of the capacity of Boston Harbor, and of the most suitable mode of improving its conveniences for commerce, is obtained by comparing it with London in some particulars; and this comparison is suggested by the Report of the Commissioners of January, 1850. It is recommended in this report to excavate upon the flats wet docks, in imitation of London and Liverpool, and a plan is submitted in which the place of these docks is drawn, above low-water mark. This recommendation is founded upon a total misconception of the nature of the case, and ignorance of the actual condition of Boston Harbor. Wet docks have been constructed in London at an enormous cost, because they were absolutely indispensable. As the commerce enlarged, the ships that entered the river would have blocked it up, and intercepted all passage, had they not been drawn out on one side or the other. The maintenance of the commercial prosperity of the city depended on having some auxiliary space into which to take vessels that must unavoidably lie still a long time, while discharging, loading, repairing, &c. The natural room was too limited; artificial room was to be created. In the case of Liverpool, docks are required, whatever may be their expense, if a great trade is to be sustained, in consequence of the want of good anchoring-ground in the Mersey, and because it would not under any circumstances be either safe or commodious for vessels to load and discharge cargoes by the side of a pier, or by means of lighters, where the rise and fall of the tide is thirty feet. The cases, therefore, of Boston and London, or Liverpool, are essentially different.

Neither is it correct to speak of the Atlantic Dock at New York as belonging to the same system as the English docks. The Atlantic Dock is formed by the inclosure of a natural water area, deepened and improved undoubtedly. It is hardly worth while to say, that this is a very distinct thing from the construction of one of the London docks, occupying ground on which formerly stood a populous parish, with its dwellings and churches.

But while the London docks do not furnish us an example for imitation, we may copy with advantage the plan of the Atlantic Dock. The water area of the London docks is about one hundred and eighty-eight acres. Now the whole amount of the water area of the Fore Point Channel, including the space between the wharves, added to that of the two Mystic Channels, is about the same as the water area of the London docks. So far, then, from being called upon to excavate wet docks on the South Boston Flats at an incalculable cost, we have merely to inclose these channels suitably, and maintain them in a good state, to have at once a protected water area equal to that of the London docks, but having this remarkable superiority; that by far the greater portion of it is provided with natural reservoirs of back-water, which, if properly treated, will serve always to keep it open. And to all this is still to be added Chelsea Great Creek, the water area of which is in itself equal in amount to that of the London docks, and which, though it has no rear receptacle, possesses in its natural state every advantage of security that art could bestow.

It is painful to see opinions so erroneous, upon a subject of such vast importance as the preservation of Boston Harbor, and the improvement of its commercial accommodations, officially and formally laid before the Legislature of the State.

If the Fore Point Channel were appropriately walled in, (there being already sufficient wharf-room,) and if the proper accessories were provided, there is no reason why it should not, considering its convenience and proximity, take the place in Boston Harbor of the Atlantic Dock in New York. At present it exhibits a melancholy spectacle of resources wasted and opportunities unimproved.

Regret is sometimes expressed that so large a quantity of the tidal marshes and mudlands should have been filled during the present century. But this operation was the necessary concomitant of the growth of the city, and indeed the very mode of its prosperity and increase. The statesmen and political economists of the day would not have hesitated to sanction and encourage the schemes of aggrandizement of enterprising and sagacious projectors, even if they had foreseen that one of their results would be the loss of water capacity in the main channels of the harbor. Their part was to lay the foundations of our commercial greatness; one of the duties devolved upon us is to preserve and improve the instruments of commerce; and with prudent measures we shall always have it in our power to secure to Boston Harbor its present reputation of being one of the safest and most commodious in the world.